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Potentiodynamic polarization study of the corrosion characteristics of acid mine drainage

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Abstract: Potentiodynamic tests were carried out to evaluate the attacking characteristics of acid mine drainage (AMD) from South African mines. Tests were done using seven solutions of:- AMD water taken from the field and consisting of two AMD sources from the gold mines and two sources from the coal mines; sulphuric acid, distilled water, synthetic AMD prepared in the laboratory. Tests were done at normal room temperature of 23°C using mild steel and stainless steel samples.

Tafel plots were generated and corrosion current (I_{corr}), corrosion potential (E_{corr}), corrosion rates determined in each case. The corrosion rate of AMD from the coal mines was found to be similar to the corrosion of AMD from the gold tailings dam mine, both of which were significantly higher than the corrosion of AMD from the underground gold mine. It is, however, anticipated that the corrosion bevaviour could be different under static conditions and further investigations in this regard are being conducted.

Keywords. Corrosion current, potential, acid mine drainage, potentiodynamic, polarization

Introduction

With or without the presence of acid mine drainage, the mining environment is typically toxic and give rise to severe corrosion problems. But corrosion from mine-related activities becomes a much more enormous problem when acid mine drainage occurs, causing adverse effects to the environment, ecology and structural materials of engineering construction. It is well established that the pyritic ores exposed during mining, will over the years oxidise upon exposure to atmospheric conditions of oxygen and moisture. This normally happens several years after abandonment of mining activity. It is therefore usual that most problems of acid mine drainage are reported in abandoned mines.

In addition to the chemical process of AMD formation, iron and sulphide oxidizing bacteria are known to play a significant role in advancing AMD [1]. The Thiobacillus Ferro-oxidans and Thiobacillus Thioxidans feed on the iron and sulphate found in the pyrites respectively, consequently accelerating the oxidation of these salts.

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Thiobacillus Thioxidans do not cause major influence but iron-feeding bacteria, typically crenothrix, gallionella, and others that use iron as an energy source that is fed upon and stored in their microbial protoplasm, tends to accelerate the oxidation of iron into ferric ion or rust.

The acidic and humid conditions in mines can be highly aggressive and may cause severe levels of corrosion in mining equipment infrastructure elements. Some of the common equipment that could experience corrosion problems are [2,3] piping systems and pumps which are widely used in underground mining operations, tunnel roof bolts, wire ropes for equipment, machinery and materials transportation assemblages, ore processing plants and structures. Other forms of infrastructure that could be affected include water handling equipment, pipes and dams [4]; highway structures

This paper presents an experimental study that was conducted using electrochemical polarization tests to assess the attacking nature of the AMD from coal mines and gold mines. The information generated through the study would provide understanding of the aggressiveness of the acid mine drainage attack on metals.

1. Experimental

The corrosion experiments were conducted by means of electrochemical polarization tests done with seven types of AMD solutions, and two types of steel consisting of mild steel and stainless steel. The experiment serves to provide rapid evaluation of the characteristics of corrosion behaviour of metals under the influence of AMD. Mild steel is a widely used structural material in civil engineering applications while stainless steel commands interest with respect to corrosion resistance. The chemical compositions of steel samples that were used in the corrosion study are given in Table 1.

Table 1. Chemical composition of mild steel and stainless steel samples

	Fe	C	Si	P	Mn	Cu	Al	Ni	Cr	Va
Mild steel	99.52	0.047	0.013	<0.005	0.24	0.013	0.044	0.008	0.026	<0.005
Stainless steel	70.84	0.049	0.49	0.027	1.20	0.39	<0.005	8.48	18.3	0.068

The six different media solutions that were used in the potentiodynamic tests, consisted of two AMD sources AMD-Wz, AMD-Lc from the gold mines; two AMD water sources AMD-MpK, AMD-MpT from the coal mines; synthetic AMD 3000/2.5 and sulphuric acid H_2SO_4/1.

Corrosion is an electrochemical process. Accordingly, rapid electrochemical techniques are typically applied to examine the process kinetics and the influence of environmental conditions. The test method allows measurement of instantaneous corrosion rates for metals under study which can be used to assess the corrosion resistance of the material. Such tests are also done in reinforced concrete structures subject to carbonation and/or chloride-induced corrosion attack. The instrument used in this investigation was an AUTOLAB PGSTAT 10 Electrical potentiostat with a glass corrosion cell, Ag/AgCl type reference electrode filled with 3M KCl solution. Installed in the instrument was the NOVA version 1.7 software that was used to perform data capture and analyses throughout the tests. The working electrode consisted of specimens of 10 x 10 x 3 mm thick coupons. The specimens were mounted in epoxy resin moulds and the exposed surface area of the mounted coupon was measured. The working electrodes were then exposed to the test solution media and tests runs were then conducted at a scan rate of 0.1 mV/s, in order to obtain potentiodynamic anodic and cathodic polarization curves. The values of corrosion current (I_{corr}) and corrosion potential (E_{corr}) were determined from the Tafel plots of polarization curves. The I_{corr} is determined by extrapolating the linear portions of the anodic and cathodic curves of the Tafel plot. The I_{corr} values may also be used to calculate the corrosion rates. The polarisation resistance is related to the I_{corr} according to the Stern-Geary expression:

$$I_{corr} = \frac{\beta_a \, x \, \beta_c}{2.3(\beta_a + \beta_c)\, R_p} = B / R_p$$

Where β_a, β_c are anodic and cathodic Tafel constants. The corrosion rate (in μm/yr) for mild steel can be calculated from [5]

$$CR = 11x10^6.B / R_p.A$$

Knowing that 1 amp-hr consumes 1.04g Fe, the mass loss of steel can also be estimated from I_{corr}.

2. Results and discussion

The Tafel plots (potentiodynamic polariation curves) were determined for mild steel and for stainless steel corrosion in the various AMD aqueous test solutions. Figures 1 and 2 show the polarization curves for mild steel in AMD-Lc and AMD-Wz respectively. From the Tafel plots, the values of parameters E_{corr}, I_{corr}, Tafel constants β_a (anode slope) and β_c (cathode slope), Rp, and corrosion rate were determined as given in Table 2.

The potentiodynamic polarization measurements provide an assessment of corrosion behaviour under dynamic conditions. The measurements are instantaneous and provide rapid measurement of reactions involving rapid electron transfer. The pH range of the various AMD water is fairly close (2.6 to 3.1pH) and may not dominate corrosion influence. The relative corrosion behaviour between the AMD water types is likely to be largely determined by the differences in types and concentrations of elements or ions present in the AMD. As expected from classic corrosion theory, the lower pH of the aqueous solutions caused a right shift in the Tafel plots, directly increasing I_{corr} with increase in the acidity. This strong trend can be seen in Figure 3. The highly negative E_{corr} potentials of mild steel place the electrochemical reactions in the active regions. Some interesting observations can be seen with AMD-Wz. While its E_{corr} value is within the same range as the other AMD solutions, the sharply low current density led to relatively very low corrosion rate of 1.75 mm/yr, compared to 6.26 and 9.86 mm/yr for AMD-Lc and AMD –MpK.

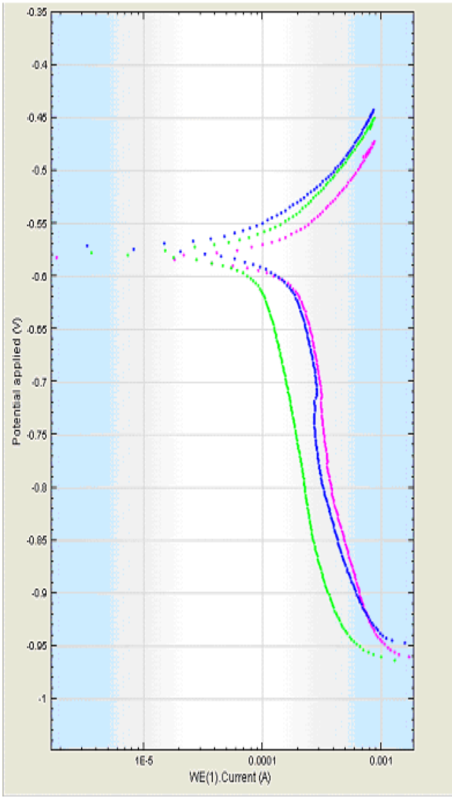

Figure 1. Potentiodynamic polarization curves for mild steel in AMD-Lc

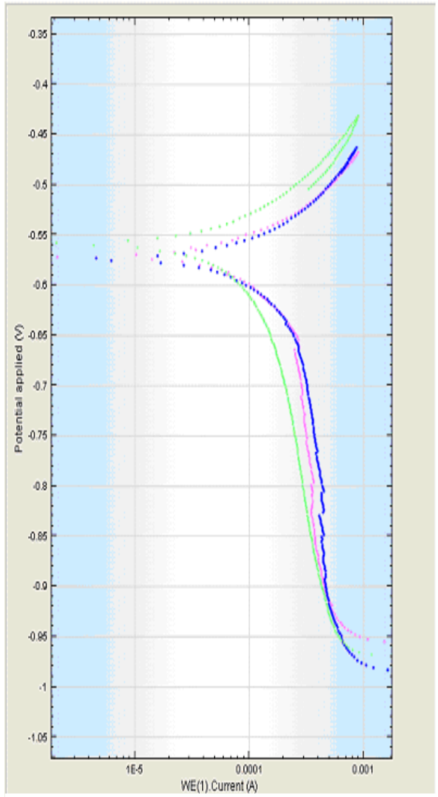

Figure 2. Potentiodynamic polarization curves for mild steel in AMD-Wz

Unlike for static immersion tests, the dynamic conditions (solution agitation) of the potentiodynamic polarization measurements can be expected to increase corrosion rate. As such, the measured potentiodynamic rates of corrosion of 2 to 24 mm/yr, observed in the aqueous test solutions, are likely to be significantly higher than the rates for the static immersion tests determined at normal temperatures. From the potentiodynamic measurements, the ranking of corrosion in decreasing order is H_2SO_4 > AMD-MpK > AMD-Lc > AMD-Wz. The observed trends underscore the complexity of corrosion behaviour of metals under the influence of the metal characteristics, environmental conditions, and the aqueous solutions or the element concentrations in the solutions, for that matter.

The stainless steel showed positive (nobler) corrosion potentials and small current density, implying passivity as indicated by the generally negligible corrosion rates. Again the AMD-Wz, showed greater corrosive activity on stainless steel than the counterpart solutions of AMD-Lc and AMD-MpK. Clearly, the corrosive actions of AMD on metals are quite complex, being influenced by the metal characteristics in conjunction with exposure conditions.

Table 2. Potentiodynamic corrosion parameters for mild steel and stainless steel in acid mine drainage water

Sample	Aqueous solution	pH	β_a (mV)	β_c (mV)	E_{corr} (mV)	I_{corr} (mA)	Corrosion rate (mm/year)
Mild steel	AMD-Lc	2.6	69.1	248.0	-577.6	547.7	6.26
	AMD-Wz	3.1	508.2	135.7	-568.0	150.7	1.75
	AMD-MpK	3.0	-454.1	186.6	-586.7	545.2	6.39
	3000/2.5	2.5	246.6	110.2	-505.1	848.2	9.86
	H_2SO_4	1.0	-879.9	426.6	-604.2	2024.7	23.53
Stainless steel	AMD-Lc	2.6	278.6	787.0	179.5	2.8	0.03
	AMD-Wz	3.1	582.6	-1074.4	163.3	25.2	0.29
	AMD-MpK	3.0	274.4	578.4	118.6	1.3	0.02

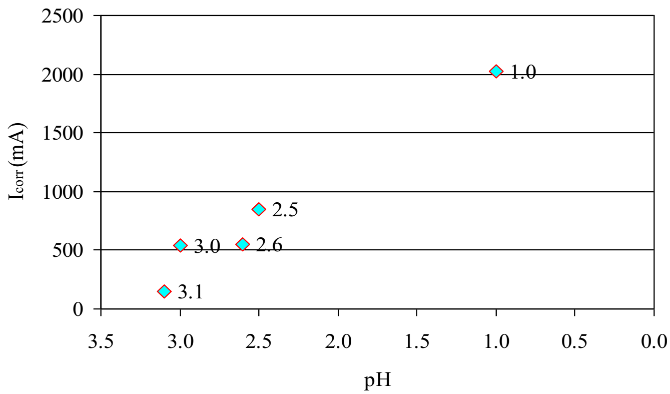

Figure 3. Right shift of Tafel plots showing a direct increase in the I_{corr} with decrease in pH of the aqueous solutions

3. Conclusions

The corrosion of metals by acidic mine water from various sources was evaluated in the foregone investigation using electrochemical polarisation tests. Mild steel and stainless steel coupons were used in the investigation with a view of assessing the corrosivity of AMD from the coal mines and gold mines of South Africa. These AMD water sources consisted of underground gold mines, gold tailings, open pit coal mines.

From the potentiodynamic measurements, the ranking of corrosion attack by AMD, in decreasing order is AMD-MpK > AMD-Lc > AMD-Wz, with corrosion rates of 6.39, 6.26, 1.75 mm/yr respectively. As expected, sulphuric acid gave the highest corrosion rate while stainless steel showed negligible corrosion rates. However, it may be recalled that under dynamic conditions of the polarization tests, corrosion behaviour may be different than tests conducted under static conditions.

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